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SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

10 Be it known that I, ROBERT C. LAM, a citizen of the United States,
resident of Rochester, County of Oakland, State of Michigan have invented a
new and useful improvement in a

**FRICTION MATERIAL CONTAINING PARTIALLY CARBONIZED CARBON
FIBERS**

15

which invention is fully set forth in the following specification.

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DESCRIPTION

FRICION MATERIAL CONTAINING PARTIALLY CARBONIZED CARBON FIBERS

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TECHNICAL FIELD

The present invention relates to a non-asbestos, non-metallic fibrous base material comprising partially carbonized carbon fibers either as a surface layer of a two-layer friction material or as a component in a single layer friction material. The invention further relates to a composite friction material comprising the above described fibrous base material impregnated with a phenolic resin or a phenolic based resin blend.

The friction material of the present invention has improved coefficient of friction characteristics and improved strength, porosity, wear resistance and noise resistance.

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BACKGROUND ART

New and advanced transmission systems and braking systems are being developed by the automotive industry. These new systems often involve high energy requirements. Therefore, the friction materials technology must be also developed to meet the increasing energy requirements of these advanced systems.

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In particular, a new high energy type friction material is needed. The new high energy friction material must be able to withstand high speeds wherein surface speeds are up to about 65m/seconds. Also, the friction material must be able to withstand high facing lining pressures up to about 1500 psi. It is also important that the friction material be useful under limited lubrication conditions.

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5 The friction material must be durable and have high heat resistance in order to be useful in the advanced transmission and braking systems. Not only must the friction material remain stable at high temperatures, it must also be able to rapidly dissipate the high heat that is being generated during operating conditions.

10 The high speeds generated during engagement and disengagement of the new transmission and braking systems mean that a friction material must be able to maintain a relatively constant friction throughout the engagement. It is important that the frictional engagement be relatively constant over a wide range of speeds and temperatures in order to
15 minimize "shuddering" of materials during braking or the transmission system during power shift from one gear to another. It is also important that the friction material have a desired torque curve shape so that during frictional engagement the friction material is noise or "squawk" free.

 In particular, transmission and torque-on-demand systems
20 incorporate slipping clutches mainly for the fuel efficiency and driving comfort. The role of the slip clutch within these systems varies from vehicle launching devices, such as wet start clutches, to that of a torque converter clutches. According to the operating conditions, the slip clutch can be differentiated into three principle classes: (1) Low Pressure and
25 High Slip Speed Clutch, such as wet start clutch; (2) High Pressure and Low Slip Speed Clutch, such as Converter Clutch; and (3) Extreme Low Pressure and Low Slip Sped Clutch, such as neutral to idle clutch.

 The principal performance concerns for all applications of the slip clutch are the prevention of shudder and the energy management of the
30 friction interface. The occurrence of shudder can be attributed to many factors including the friction characteristics of the friction material, the mating surface's hardness and roughness, oil film retention, lubricant chemistry and interactions, clutch operating conditions, driveline assembly and hardware alignment, and driveline contamination. The friction

5 interface energy management is primarily concerned with controlling interface temperature and is affected by the pump capacity, oil flow path and control strategy. The friction material surface design also contributes to the efficiency of interface energy management.

Previously, asbestos fibers were included in the friction material for
10 temperature stability. Due to health and environmental problems, asbestos is no longer being used. More recent friction materials have attempted to overcome the absence of the asbestos in the friction material by modifying impregnating paper or fiber materials with phenolic or phenolic-modified resins. These friction materials, however, do not rapidly dissipate the high
15 heat generated, and do not have the necessary heat resistance and satisfactory high coefficient of friction performance now needed for use in the high speed systems currently being developed.

The present invention is an improvement over the Smith et al US Patent No. 5,965,659 reference which involves the use of carbonaceous
20 fibers derived from oxidized polyacrylonitrile based fibers.

The present invention is also an improvement over the Seitz U.S. Patent No. 5,083,650 reference which involves a multi-step impregnating and curing process; i.e., a paper impregnated with a coating composition, carbon particles are placed on the paper, the coating composition in the
25 paper is partially cured, a second coating composition is applied to the partially cured paper, and finally, both coating compositions are cured.

In other friction materials, metallic fibers combined with carbon materials were included in the friction material for wear resistance. For example, Fujimaki et al. U.S. Patent No. 4,451,590 describes a friction
30 material having metallic fibers, filler, carbon particles, carbon fibers and phenolic resin. However, the metallic based friction materials do not have sufficient porosity and compressibility to be capable of high fluid permeation capacity during use. Also, the metallic based friction materials are not sufficiently resilient or elastic, yet resistant to compression set to

5 be capable of withstanding high facing lining pressures of up to about 1500 psi (approximately 105 kg/cm²). The metallic based friction material also is not capable of withstanding high surface speeds of up to about 65 m/second which are generated during engagement and disengagement of the new transmission and braking systems.

10 The present invention is also an improvement over earlier co-owned patents by the assignee herein, BorgWarner Inc., for friction materials. In particular, U.S. Patent No. 5,998,307 relates to a friction material having a base impregnated with a curable resin where a porous primarily layer comprises at least one fibrous material and a secondary layer comprises
15 carbon particles covering at least about 3 to about 90% of the surface of the primary layer. The U.S. Patent No. 5,858,883 relates to a base material having a primary layer of less fibrillated aramid fibers, synthetic graphite, and a filler, and a secondary layer comprising carbon particles on the surface of the primary layer. U.S. Patent No. 5,856,224 relates to a
20 friction material comprising a base impregnated with a curable resin. The primary layer comprises less fibrillated aramid fibers, synthetic graphite and filler; the secondary layer comprises carbon particles and a retention aid. The U.S. Patent No. 5,958,507 relates to a process for producing the friction material where at least one surface of the fibrous material which
25 comprises less fibrillated aramid fibers is coated with carbon particles and a retention aid when at least 3 to 90% of the surface, impregnating with a phenolic or modified phenolic resin and curing. The U.S. Patent No. 6,001,750 relates to a friction material comprising a fibrous base material impregnated with a curable resin. The porous primarily layer comprises
30 less fibrillated aramid fibers, carbon particles, carbon fibers, filler material, phenolic novoloid fibers, and optionally, cotton fibers. The secondary layer comprises carbon particles which cover the surface at about 3 to about 90% of the surface. The U.S. Patent No. 6,630,416 issued October 7, 2003 relates to a friction material formed by the deposition of silica friction

- 5 modifiers on a porous primary layer to form high, wet energy carbonaceous friction materials.

It is to be understood that the various primary layers described in the BorgWarner patents and applications referenced herein are useful with the present invention and are fully incorporated herein by reference.

- 10 In addition, various base materials, as described in commonly owned BorgWarner Inc. U.S. Patent Nos. 5,753,356 and 5,707,905 (which describe base materials comprising less fibrillated aramid fibers, synthetic graphite and filler) are also contemplated as being useful with the present invention and as such are fully incorporated herein by reference. Yet
15 another commonly owned patent US Pat. No. 6,130,176 issued Oct. 10, 2000, relates to non-metallic fibrous base materials comprising less fibrillated aramid fibers, carbon fibers, carbon particles and filler and is also considered to be useful as a primary layer in the present invention and is fully incorporated herein by reference.

- 20 In order for friction materials to be useful in "wet" applications, the friction material must have a wide variety of acceptable characteristics. The friction material must be resilient or elastic yet resistant to compression set, abrasion and stress; have high heat resistance and be able to dissipate heat quickly; and, have long lasting, stable and consistent
25 frictional performance. If any of these characteristics are not met, optimum performance of the friction material is not achieved.

- It is also important that a suitable impregnating resin be used with the fibrous base material in order to form a high energy application friction material. The friction material must have good shear strength both when
30 saturated with the wet resin during impregnation and when saturated with brake fluid or transmission oil during use.

It is also important, under certain applications, that the friction material have high porosity such that there is a high fluid permeation capacity during use. Thus, it is important that the friction material not only

5 be porous, it must also be compressible. The fluids permeated into the friction material must be capable of being squeezed or released from the friction material quickly under the pressures applied during operation of the brake or transmission, yet the friction material must not collapse. It is also important that the friction material have high thermal conductivity to also
10 help rapidly dissipate the heat generated during operation of the brake or transmission.

As far as is known, there is no disclosure of an anti-shudder friction material for use in transmission systems which includes a fibrous base material comprising partially carbonized carbon fibers either as a secondary
15 layer, or, in other embodiments, as a component in a single layer friction material.

Accordingly, it is an object of the present invention to provide an improved friction material with reliable and improved properties compared to those of the prior art.

20 A further object of this invention is to provide friction materials with improved coefficient of friction characteristics and high thermal conductivity.

As a result of extensive research in view of the need for a better friction material, a friction material with improved characteristics has been
25 developed by the invention. The present wet friction material is useful in "wet" applications where the friction material is "wetted" or impregnated with a liquid such as brake fluid or automatic transmission fluid during use.

During use of the "wet" friction material, the fluid is ultimately squeezed from or is impregnating the friction material. Wet friction materials differ
30 greatly, both in their compositions and physical characteristics from "dry" friction materials.

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DISCLOSURE OF THE INVENTION

In order to achieve the requirements discussed above, many materials were evaluated for friction and heat resistant characteristics under conditions similar to those encountered during operation. Both commercially available brake linings and transmission materials were investigated and proved not to be suitable for use in high energy applications.

The present invention is especially useful in brakes and in clutch applications. The present invention provides a fibrous base material with an optimum amount partially carbonized carbon fibers.

15 In one aspect, the present invention relates to a friction material having a primary layer comprising a fibrous base material comprising aramid fibers alone and/or combinations of at least one or less fibrillated aramid fibers, cotton fibers, carbon fibers, carbon particles and at least one filler material and, optionally, other ingredients, and a secondary layer
20 comprising partially carbonized carbon fibers. In certain embodiments, the extent of carbonization of the carbon fibers is about 65% to about 90%. Also, in certain embodiments, the partially carbonized fibers are present at about 10 to about 30%, by weight, and preferable about 15 to about 25%. The partially carbonized carbon fibers preferable have an average
25 fiber length of about 0.5 to about 6 mm and a fiber diameter of about 1 to about 15 μ m.

The partially carbonized carbon fibers provide the friction material with good heat conduction such that the friction material has desired heat resistance. The partially carbonized carbon particles also provide the
30 friction material with good friction characteristics such as a good or smooth "feel" in shift and essentially noise or "squawk" free operation of the brakes and clutches. In certain embodiments, the presence of a small relative amount of cotton fibers provides the friction material with desired

- 5 "break-in" characteristics such that there is little or no shudder occurring during the initial use of the friction material.

In embodiments where two layers are formed, the secondary, or top, layer of the partially carbonized carbon fibers are deposited on the primary layer to form the fibrous base material. The secondary layer can also
10 contain various friction modifying particles which are also useful in the secondary layer on the fibrous base material. In particular, silica particles such as diatomaceous earth, celite, celatom, and/or silicon dioxide are especially useful. The surface friction modifying particles are present at about 0.2 to about 20%, by weight, and preferably about 2-10%, by
15 weight, and most preferably about 3-5%, by weight, of the fibrous base material.

The fibrous base material can be impregnated using different resin systems. In certain embodiments, it is useful to impregnate the fibrous based material with a phenolic resin or a modified phenolic-based resin. In
20 certain embodiments, when a silicone resin is blended or mixed with a phenolic resin in compatible solvents and that silicone-phenolic resin blend is used to impregnate a fibrous base material of the present invention, an especially useful high energy friction material is formed.

25 BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 is a graph of slip clutch material performance showing a good curve shape for a material at cycle 50 and at cycle 2000.

Fig. 2 is a schematic diagram showing one method for making a friction material according to the present invention.

30 Fig. 2a is a graph showing the compression behavior of BW, the friction material of the present invention, and a woven carbon fabric material.

Fig. 3 is a graph showing the high speed slip durability bench test (P25) for the conventional material, M1.

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Fig. 5 is a graph showing the high speed slip durability bench test (P25) for a woven carbon fabric material.

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Figs. 10 and 11 are graphs showing a dynamometer test (the engine torque, clutch pressure, output torque and slip speed) for the friction material of the present invention, BW at 45,000 cycles (Fig. 10) and at 77,000 cycles (Fig. 11).

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The friction material of the present invention has improved coefficient of friction characteristics. Also, the friction material has improved elasticity and porosity which allows for more uniform heat dissipation during use of the friction material. The fluid in the transmission

5 or brake can rapidly move through the porous structure of the friction material. Further, the increased elasticity provides more uniform pressure or even pressure distribution on the friction material such that uneven lining wear or separator plate "hot spots" are eliminated.

The more porous the structure of the friction material, the more
10 efficient is the heat dissipation. The oil flow in and out of the friction material during engagement of the friction material during use occurs more rapidly when the friction material is porous.

Various methods for impregnating the friction materials of the present invention can be used. The fibrous base material is impregnated
15 with the phenolic or phenolic based resin, preferably so that the impregnating resin material comprises about 45 to about 65 parts, by weight, per 100 parts, by weight, of the friction material. After the fibrous base material has been impregnated with the resin, the impregnated fibrous base material is heated to a desired temperature for a predetermined length
20 of time to form the friction material. The heating cures the phenolic resin at a temperature of about 300°F. When other resins are present, such as a silicone resin, the heating cures the silicone resin at a temperature of about 400°F. Thereafter, the impregnated and cured friction material is adhered to the desired substrate by suitable means.

25 Various resins useful in impregnating the fibrous base material include phenolic resins and phenolic-based resins. It is to be understood that various phenolic-based resins which include in the resin blend other modifying ingredients, such as epoxy, butadiene, silicone, tung oil, benzene, cashew nut oil and the like, are contemplated as being useful
30 with the present invention. In the phenolic-modified resins, the phenolic resin is generally present at about 50% or greater by weight (excluding any solvents present) of the resin blend. However, it has been found that friction materials, in certain embodiments, can be improved when the impregnant resin blend contains about 5 to about 80%, by weight, and for

5 certain purposes, about 15 to about 55%, and in certain embodiments about 15 to about 25%, by weight, of silicone resin based on the weight of the silicone-phenolic mixture (excluding solvents and other processing acids).

10 Examples of useful phenolic and phenolic-silicone resins useful in the present invention are disclosed in the above-referenced BorgWarner U.S. patents which are fully incorporated herein, by reference. Silicone resins useful in the present invention include, for example, thermal curing silicone sealants and silicone rubbers. Various silicone resins are useful with the present invention. One resin, in particular, comprises xylene and
15 acetylacetone (2,4-pentanedione). The silicone resin has a boiling point of about 362°F (183°C), vapor pressure at 68°F mm, Hg: 21, vapor density (air = 1) of 4.8, negligible solubility in water, specific gravity of about 1.09, percent volatile, by weight, 5% evaporation rate (ether = 1), less than 0.1, flash point about 149°F (65°C) using the Pensky-Martens method. It is to
20 be understood that other silicone resins can be utilized with the present invention. Other useful resin blends include, for example, a suitable phenolic resin comprises (% by wt.): about 55 to about 60% phenolic resin; about 20 to about 25% ethyl alcohol; about 10 to about 14% phenol; about 3 to about 4% methyl alcohol; about 0.3 to about 0.8%
25 formaldehyde; and, about 10 to about 20% water. Another suitable phenolic-based resin comprises (% by wt.): about 50 to about 55% phenol/formaldehyde resin; about 0.5% formaldehyde; about 11% phenol; about 30 to about 35% isopropanol; and, about 1 to about 5% water.

It has also been found that another useful resin is an epoxy modified
30 phenolic resin which contains about 5 to about 25 percent, by weight, and preferably about 10 to about 15 percent, by weight, of an epoxy compound with the remainder (excluding solvents and other processing aids) phenolic resin. The epoxy-phenolic resin compound provides, in

5 certain embodiments, higher heat resistance to the friction material than the phenolic resin alone.

In certain embodiments, it is preferred that the target pick up of resin by the fibrous base material range from about 40 to about 65%, and, in certain embodiments, about 60 to at least 65%, by weight, total
10 silicone-phenolic resin. After the fibrous base material is impregnated with the resin, the fibrous base material is cured for a period of time (in certain embodiments for about 1/2 hour) at temperatures ranging between 300-400°C to cure the resin binder and form the friction material. The final
15 thickness of the friction material depends on the initial thickness of the fibrous base material and, in certain embodiments, preferably ranges from about 0.014" to about 0.040".

It further contemplated that other ingredients and processing aids known to be useful in both preparing resin blends and in preparing impregnating fibrous-based materials can be included in the friction
20 materials.

Both the silicone resin and the phenolic resin are present in solvents which are compatible to each other. These resins are mixed together (in preferred embodiments) to form a homogeneous blend and then used to impregnate a fibrous base material. There is not the same effect if a
25 fibrous base material is impregnated with a phenolic resin and then a silicone resin is added thereafter or vice versa. There is also a difference between a mixture of a silicone-phenolic resin solution, and emulsions of silicone resin powder and/or phenolic resin powder. When silicone resins and phenolic resins are in solution they are not cured at all. In contrast,
30 the powder particles of silicone resins and phenolic resins are partially cured. The partial cure of the silicone resins and the phenolic resins inhibits a good impregnation of the fibrous base material.

In certain embodiments of the present invention, the fibrous base material is impregnated with a blend of a silicone resin in a solvent which

5 is compatible with the phenolic resin and its solvent. In one embodiment, isopropanol has been found to be an especially suitable solvent. It is to be understood, however, that various other suitable solvents, such as ethanol, methyl-ethyl ketone, butanol, isopropanol, toluene and the like, can be utilized in the practice of this invention. The presence of a silicone resin, 10 when blended with a phenolic resin and used to impregnate a fibrous base material, causes the resulting friction materials to be more elastic than fibrous base materials impregnated only with a phenolic resin. When pressures are applied to the silicone-phenolic resin blended impregnated friction material of the present invention, there is a more even distribution 15 of pressure which, in turn, reduces the likelihood of uneven lining wear. After the silicone resin and phenolic resin are mixed together, the mixture is used to impregnate a fibrous base material.

In certain embodiments, less fibrillated fibers and partially carbonized carbon fibers are used in the fibrous base material to provide a desirable 20 pore structure to the friction material which, in turn, provides increased thermal resistance to the friction material. The fiber geometry not only provides increased thermal resistance, but also provides delamination resistance and squeal or noise resistance. The presence of the partially carbonized carbon fibers aids in increasing the thermal resistance, 25 maintaining a steady coefficient of friction and increasing the squeal resistance. Also, in certain embodiments, a relatively low amount of cotton fibers in the fibrous base material improves the friction material's clutch "break-in" characteristics.

The use of less fibrillated aramid fibers in a fibrous base material 30 improves the friction material's ability to withstand high temperatures. Less fibrillated aramid fibers generally have few fibrils attached to a core fiber. The use of the less fibrillated aramid fibers provides a friction material having a more porous structure; i.e., there are more and larger pores than if a typical fibrillated aramid fiber is used. The porous structure

5 is generally defined by the pore size and liquid permeability. In a preferred embodiment, the fibrous base material defines pores ranging in mean average size from about 2.0 to about 25 microns in diameter. In certain embodiments, the mean pore size ranges from about 2.5 to about 8 microns in diameter and the friction material had readily available air voids
10 of at least about 50% and, in certain embodiments, at least about 60% or higher.

When the friction material has a higher mean flow pore diameter and permeability, the friction material is more likely to run cooler or with less heat generated in a transmission due to better automatic transmission fluid
15 flow throughout the porous structure of the friction material. During operation of a transmission system, oil deposits on the surface of the friction material tend to develop over time due to a breakdown of the automatic transmission fluid, especially at high temperatures. The oil deposits on the fibers decrease the pore openings. Therefore, when the
20 friction material initially starts with larger pores, there are more open pores remaining during the useful life of the friction material. In addition, in embodiments at least partially impregnated with a silicone resin, the silicone resin, due its elastic characteristics, allows the fibers in the friction material to have an even more open structure.

25 It is desired that the aramid fibers have a length ranging from about 0.5 to about 10 mm and a Canadian Standard Freeness (CSF) of greater than about 300. In certain embodiments, it is desired to use less fibrillated aramid fibers which have a CSF of about 450 to about 550 preferably about 530 and greater; and, in other certain embodiments, about 580-650
30 and above and preferably about 650 and above. In contrast, more fibrillated fibers, such as aramid pulp, have a freeness of about 285-290.

The "Canadian Standard Freeness" (T227 om-85) means that the degree of fibrillation of fibers can be described as the measurement of freeness of the fibers. The CSF test is an empirical procedure which gives

5 an arbitrary measure of the rate at which a suspension of three grams of
fibers in one liter of water may be drained. Therefore, the less fibrillated
aramid fibers have higher freeness or higher rate of drainage of fluid from
the friction material than other aramid fibers or pulp. Friction materials
comprising the aramid fibers having a CSF ranging from about 430-650
10 (and in certain embodiments preferably about 580-640, or preferably about
620-640), provide superior friction performance and have better material
properties than friction materials containing conventionally more fibrillated
aramid fibers. The longer fiber length, together with the high Canadian
freeness, provide a friction material with high strength, high porosity and
15 good wear resistance. The less fibrillated aramid fibers (CSF about 530-
about 650) have especially good long-term durability and stable
coefficients of friction.

Various fillers are also useful in the primary layer of the fibrous base
material of the present invention. In particular, silica fillers, such as
20 diatomaceous earth, are useful. However, it is contemplated that other
types of fillers are suitable for use in the present invention and that the
choice filler depends on the particular requirements of the friction material.

In certain embodiments, cotton fiber is added to the fibrous base
material of the present invention to give the fibrous material higher
25 coefficients of friction. In certain embodiments, about 5 to about 20%,
and, in certain embodiments, about 10% cotton can also be added to the
fibrous base material.

One example of a formulation for the primary layer of a fibrous base
material, as described in the above incorporated by reference US Pat. No.
30 6,130,176, comprises about 10 to about 50%, by weight, of a less
fibrillated aramid fiber; about 10 to about 35%, by weight, of activated
carbon particles; about 5 to about 20%, by weight, cotton fibers, about 2
to about 15%, by weight, carbon fibers; and, about 10 to about 35%, by
weight, of a filler material. In certain embodiments, one particular

5 formulation has found to be useful comprises about 35 to about 45%, by weight, less fibrillated aramid fibers: about 10 to about 20%, by weight, activated carbon particles; about 5 to about 15% cotton fibers; about 2 to about 10%, by weight, carbon fibers; and, about 25 to about 35%, by weight, filler.

10 The use of partially carbonized carbon fibers as the primary layer of the fibrous base material provides a three dimensional structure to the fibrous base material.

The uniformity of the secondary layer of the partially carbonized carbon fibers on the surface of primary layer of the fibrous base materials is achieved by using a range and size of the particles that is preferably from about 0.5 to about 6 mm in fiber length and about 1 to about 15 μ m in diameter. In these certain embodiments, it has been discovered that if the partially carbonized carbon fibers are too large or too small, the optimum three-dimensional structure not achieved and, consequently, the heat dissipation is not as optimum.

In preferred embodiments, the area of coverage of the partially carbonized carbon fibers on the primary layer surface is in the range of the about 3 to about 90% of the surface area.

The secondary layer of the partially carbonized carbon fibers is deposited on the primary layer to form the fibrous base material. In certain embodiments, the secondary layer can further include friction modifying particles. Various friction modifying particles are useful as the secondary layer on the fibrous base material. Useful friction modifying particles include silica particles; resin powders such as phenolic resins, silicone resins epoxy resins and mixtures thereof; partial and/or fully carbonized carbon powders and/or particles and mixtures thereof; and mixtures of such friction modifying particles. In particular, silica particles such as diatomaceous earth, Celite®, Celatom®, and/or silicon dioxide are especially useful. The silica particles are inexpensive organic materials which bond

5 strongly to the fibrous materials. The silica particles provide high coefficients of friction to the friction material. The silica particles also provide the friction material with a smooth friction surface and provides a good "shift feel" and friction characteristics to the friction material such that any "shudder" is minimized.

10 A preferred process for producing the friction material comprises fibers forming the primary layers of the fibrous base material. At least one surface of the primary layer of the fibrous base material is coated with the friction modifying particles. The fibrous base material with the friction modifying particles coated thereon is then impregnated with at least one
15 phenolic or phenolic-based resin. The impregnated, coated fibrous base material is cured at a predetermined temperature for a predetermined period of time to form the friction material.

One preferred embodiment for making a friction material 10 of the present invention is shown in Fig. 2. A fibrous base material 12 comprises
20 a lower layer 14 having an upper or top surface 16 and a lower or bottom surface 18. While the lower layer 14 is wet, friction modifying particles 20 are deposited onto the top surface 16 of the wet lower layer 14.

In certain methods it is also useful to use vacuum pressure (not shown) on the lower surface 18 of the wet layer 14 prior to deposition of
25 the friction modifying particles 20 on the top surface 16 of the layer 14.

It has been found that the secondary layer of the partially carbonized carbon fibers on the primary layer of the fibrous base material provides a friction material with good coefficient of friction characteristics, high durability, good wear resistance and improved break-in characteristics.

30 The following examples provide further evidence that the partially carbonized carbon fibers coated fibrous base material and resulting friction material of the present invention are an improvement over the conventional friction materials. Various preferred embodiments of the invention are

- 5 described in the following examples, which however, are not intended to limit the scope of the invention.

Examples

Slip Clutch Interface Technology Requirements: The friction
10 materials of the present invention are designed for slipping clutch applications that meet special requirements. These requirements include high mechanical strength, heat resistance, glazing resistance and shudder resistance. The friction material of the present invention has high porosity, a unique material structure for high mechanical strength, high temperature
15 conductivity, and anti-shudder friction modifier characteristics. These material characteristics are the necessary conditions of smooth slip torque output and long term friction stability.

The slip clutch material requirements for desirable slip torque response and long-term durability include good curve shape and long term
20 friction stability. The good curve shape is dependent on high material porosity and high friction modifier content. The long term friction stability is dependent on high porosity (anti-glazing) and high temperature ingredients.

The fibrous base material structure contains a porous and high
25 temperature synthetic fibers network to provide high heat dissipation and friction stability. Friction modifying particles are deposited on the fibrous base material to provide the "anti-shudder" properties. The friction material of the present invention for slip clutches is shown in Fig. 2. BW is a friction material of the present invention having a primary layer of a
30 fibrous base material comprising about 38-40%, by weight, of less fibrillated aramid fibers; about 13-15%, by weight, carbon particles; about 10-12%, by weight, cotton fibers, about 4-6%, by weight, carbon fibers; and about 28-30%, by weight, celite filler material; and having a secondary, or top layer comprising about 3% to about 5%, by weight,

- 5 celite friction modifying particles. The M1 is a conventional low-speed slip material comprising about 25%, by weight, aramid fibers; about 25%, by weight, cotton fibers; and about 15%, by weight, filler material.

Friction Characteristic Tests: Slip clutch friction materials performance and durability are evaluated by the following tests:

- 10 High speed slip durability bench test (P25): extreme high energy, extended slip durability.

Low speed slip screening bench test (P31): low speed. continuous slip, μ -v friction characteristics under various operating conditions.

Transmission dynamometer durability test.

- 15 Vehicle performance tests.

The test procedures for slip clutch materials are different from those for shifting clutch materials. The main features for the slip clutch material (such as start clutch) are that it takes a long slip time before the clutch is fully engaged, it requires high friction energy per unit contact area, and the
20 clutch carries high inertia. Table I shows the test conditions for the High Speed Slip Durability Bench Test P25 and the Low Speed Slip Screening Bench Test P31.

Table I - Test Condition for P25 and P31 Procedures

		P25	P31
		Slip Engagement	Continuous Slip
		High Speed Slip Durability	Low Speed Slip Screen
Oil Temp	(°C)	100	100
Oil Flow	(liter/min)	3	1

Cycle		2000	30
Moment of Inertia	(kg-m ²)	1.060	N/A
Slip Speed	(rpm)	3300	1 - 500
Facing Pressure	(kPa)	400	1500
Energy Density	(J/mm ²)	5.826	N/A
Cal. Stop Time	(sec)	9.75	N/A
Power	(W)	6491	5.7-2866
Power Density	(W/mm ²)	0.597	0.001-0.57

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The materials for the bench tests included BW, M1, and Carbon Fabric. BW material is the friction material of the present invention and comprises a porous, synthetic fiber network to provide high heat dissipation. In addition, friction modifiers were deposited on the surface of the BW material to provide anti-shudder properties. The M1 material is a conventional low speed slip clutch friction material and possesses moderate high-energy capacity, dense structure and lower porosity), a combination of high temperature fibers and lower temperature organic fibers and good "initial" shudder resistance. The Carbon Fabric is a woven material and has the highest porosity of all three materials. However, the carbon fabric material has high surface roughness because of the nature of weaving pattern. In addition, the carbon fabric material is most susceptible to mechanical deformation due to high compression set of the material, as shown in Fig. 2a.

A comparison of material properties for BW and M1 materials is shown in Table II below. The average pore diameter for material M1 is 4

- 5 μms . In addition to its other features, the friction material BW contains a larger pore structure, where the average pore diameter is about 7 μms . Larger pores are less susceptible to blockage through glaze formation because of their increased diameter.

	BW	M1
Porosity (%)	67.3	61.0
median pore size (μm)	7.0	4.0

- 10 Figs. 3 to 5 show the P25 bench test results for high-speed slip. Material M1 initially exhibited good torque traces (or friction coefficient μ curves), then after 500 cycles started to develop the rooster tailed torque curves clearly evident after 2000 cycles, as shown in Fig. 3. A rooster tailed torque trace is not desirable since it creates a negative μ -v curve that
- 15 is associated with shudder. Fig. 4 reveals the results of the same test against the friction material of the present invention. The output torque traces are slightly descending or flat. The μ levels are stable through the whole 2000 cycles. These characteristics, stable μ and descending/flat torque traces, of the friction material BW are strong evidence of good
- 20 performance. The test results of Carbon Fabric material are shown in Fig. 5. Fig. 5 shows clearly low μ values and huge rooster tails on every torque trace (or μ curve). This is the most undesirable case among these three tests. Similar observations and characteristics trends were observed for these three different materials using different types of automatic
- 25 transmission fluids.

The friction plates of the BW material and the M1 material, after P25 tests, were examined with the use of an SEM. It was found that material M1 suffered from the surface glazing while the friction material BW had

5 clean surface and remained porous, as shown in Fig. 6. As a low porosity material, M1 became glazed after the durability test. The high porosity of the BW friction material helps to prevent the glazing. The carbon fabric material had good energy capacity; however, the high compressibility (mechanical deformation) the surface roughness and nature of the carbon chemistry made the carbon fabric material very unstable in high energy slip durability tests, as shown in Fig. 5.

The μ -v relationship at low slip speed for materials BW, M1 and Carbon Fabric are shown in Figs. 7 to 9. The BW and M1 materials have the positive μ -v slopes, while the Carbon Fabric material exhibits negative μ -v slopes. The positive μ -v slopes are necessary for good shudder resistance. The negative μ -v slopes of the Carbon Fabric material means that the carbon fabric material will most likely produce a shudder in a vehicle. The anti-shudder ingredients in the BW and M1 materials help to create the positive μ -v slopes. The carbon itself can not provide that kind of positive μ -v slope.

A dynamometer test was conducted using a complete transmission to evaluate the durability of the transmission. The test rig was equipped with 2 engines and/or flywheel to simulate the vehicle inertia. The oil temperature was between 85-100°C. The maximum slip speed was about 2500 rpm. The clutch pressure was about 500 KPa. The slip time is about 5 seconds. The complete test was composed of 18 different types of start, each type has different conditions (slip speed, slip time, pressure etc).

Figs. 10 and 11 show the results of the dynamometer test that simulates the vehicle operation. The friction material BW has steady μ values and no shudder at the mid-test (44000 cycles) and the end of test (77,000 cycles of start). The output slip torque is linearly proportional to the input torque. No uncontrollable torque vibration was observed. These

5 results demonstrate the good quality of the friction material BW for high-speed slip clutch applications.

Figs. 12 and 13 show the vehicle test results. The friction material BW exhibited flat μ -v curves (stable μ) and smooth output torque (free of vibration). The material M1, however, showed negative μ -v slopes and
10 output torque with significant vibrations (or shudder). These data confirm the superiority of the friction material BW over the material M1 in high-speed slip applications.

INDUSTRIAL APPLICABILITY

15 The present invention is useful as a high energy friction material for use with clutch plates, transmission bands, brake shoes, synchronizer rings, friction disks or system plates.

The above descriptions of the preferred and alternative embodiments of the present invention are intended to be illustrative and are not intended
20 to be limiting upon the scope and content of the following claims.